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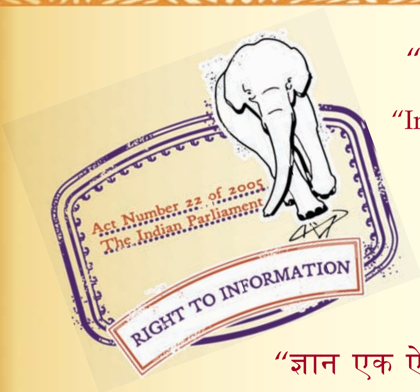

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IS : 12233 (Part 1/Sec 3) - 1987

(Reaffirmed 2003)

Indian Standard

ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS OF OVERHEAD POWER LINES AND HIGH VOLTAGE EQUIPMENT

PART 1 DESCRIPTION OF PHENOMENA

Section 3 Radio Noise Levels Due to Insulators, Fittings and Substation Equipment (Excluding Bad Contacts)

UDC 621·391·823 [621·396] : 621·315·1

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 4

August 1988

Indian Standard

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(*Continued on page* 2)

(*Continued from page* 1)

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0. FOREWORD

0.1 This Indian Standard (Part 1/Sec 3) was adopted by the Bureau of Indian Standards on 31 July 1987, after the draft finalized by the Electromagnetic Compatibility Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

0.2 The purpose of the series of Part 1 of this standard is to discuss the physical phenomena involved in the generation of electromagnetic noise fields. This also includes the main properties of such fields and their numerical values.

0.3 The technical data given in these standards will be useful aid to overhead line designers and also to any one concerned with checking of electromagnetic noise performance of a line to ensure satisfactory protection of wanted electromagnetic signals.

0.3.1 The technical data should facilitate the use of recommendations which will be given in Parts 2 and 3. These parts comprising of different sections are proposed to be issued as given below:

Part 2 Methods of measurement and procedure of determining limits
Part 3 Code of practice for minimizing the generation of radio noise

0.4 This standard is proposed to be issued in the following sections, which would clarify only one aspect over the electromagnetic interference due to overhead power lines and high voltage equipment:

Section 1 Radio noise from power lines
Section 2 Effect of corona from conductors
Section 3 Radio noise levels due to insulators, fittings and substation equipment (excluding bad contacts)

Section 4 Sparking due to bad contacts
Section 5 Special DC effects

0.5 This Standard (Part 1) has been largely based on CISPR Publication 18-1 (First Edition—1982) 'Radio interference characteristics of ovehead power lines and high voltage equipment, Part 1 Description of phenomena', issued by the International Subcommittee on Radio Interference of the International Electrotechnical Commission (IEC).

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2 - 1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard (Part 1/Sec 3) deals with the radio noise generated by insulators, fittings and substation equipment; which may cause interference to radio/TV reception.

1.2 The frequency range concerned is 0·15 to 300 MHz.

2. TERMINOLOGY

2.0 For the purpose of this standard, the definitions given in IS : 1885 (Part 36)-1972† shall apply.

3. PHYSICAL ASPECTS OF RADIO NOISE LEVELS DUE TO INSULATORS, FITTINGS AND SUBSTATION EQUIPMENT (EXCLUDING BAD CONTACTS)

3.0 Insulators, fittings and substation equipment may be the source of radio noise which may lead to radio and, in some cases, to television interference also. This may be due to various phenomena such as corona discharges in the air at insulators and fittings, surface discharges on insulators and sparks due to bad contacts. Commutation effects in ac/dc converting equipment, which can also be a source of radio noise, are discussed in Section 5.

This clause examines the phenomena of a corona and surface discharges from the physical point of view; sparks due to bad contacts are dealt within Section 4.

*Rules for rounding off numerical values (*revised*).

†Electrotechnical vocabulary: Part 36 Radio interference.

3.1 Radio Noise Due to Corona Discharges at Fittings — Corona discharges are caused by high potential gradients at certain surfaces of fittings such as suspension clamps, guard-rings or guard-horns, spacers and joints. Assuming that the voltage applied to the fittings is progressively increased, numerous different discharge processes occur. Only some of these are able to generate radio noise, but all are luminous to some extent and contribute to corona losses. The phenomena are similar to those described in 3 of Part 1/Sec 2 of this standard, in respect of conductors. Similarly, in this case, various corona modes occur, depending on the voltage applied and in the following sequence: onset streamer, glow and pre-breakdown streamer for positive corona; Trichel or negative pulses, glow, and pre-breakdown streamer for negative corona. A glow discharge does not produce radio noise but onset streamers do. Trichel pulses produce low levels of radio noise but pre-breakdown streamers produce very high levels at very high voltages.

The highest noise levels occur with modes corresponding to the pre-breakdown streamer, both positive and negative; however, these phenomena take place at much higher gradients than those corresponding to normal voltages and are therefore of little practical interest.

As in the case of conductors, radio noise from fittings tends to increase in high humidity or rain, as a result of increase in local gradients due to the presence of drops of water on the surface of the fittings.

3.2 Radio Noise due to Insulators — Insulator noise may be due to various reasons, most of which are associated with phenomena occurring at their surface, for example, small discharges due to enhanced local gradients, corona discharges due to uneveness created by dry deposits or drops of water, or sparks across dry bands caused by leakage currents on polluted insulators. Only in special cases, for example defective insulators, is the noise due to phenomena occurring inside the insulator, that is to say, sparking in internal voids or punctures. However, radio noise can result from discharges between the cement and porcelain or glass and may occur if small air gaps are present at this margin.

When the surface of an insulator is clean and dry, the current pulses at the origin of the radio noise are caused by discharges in areas of high potential gradient, depending on the geometry and material of the insulator and on the type of bonding to the cap and to the pin. Figure 1 shows by way of an example, the equipotential lines, expressed as a fraction of the applied voltage, in a cross-section of a clean and dry insulator unit.

It should be noted that these lines are much more concentrated and therefore, the gradients are higher, near the cap and pin, where the discharges that cause the noise actually occur. The values of local potential gradients in an insulator unit, and therefore the noise levels,

depend on the values of the voltage applied to the unit and, in the case of insulators consisting of several units, they also depend on the voltage distribution along the insulator string. This distribution tends to be less uniform as the number of units increases and, consequently, for the longer insulator strings or post insulators, it is necessary to have devices, such as metal rings, to improve the voltage distribution.

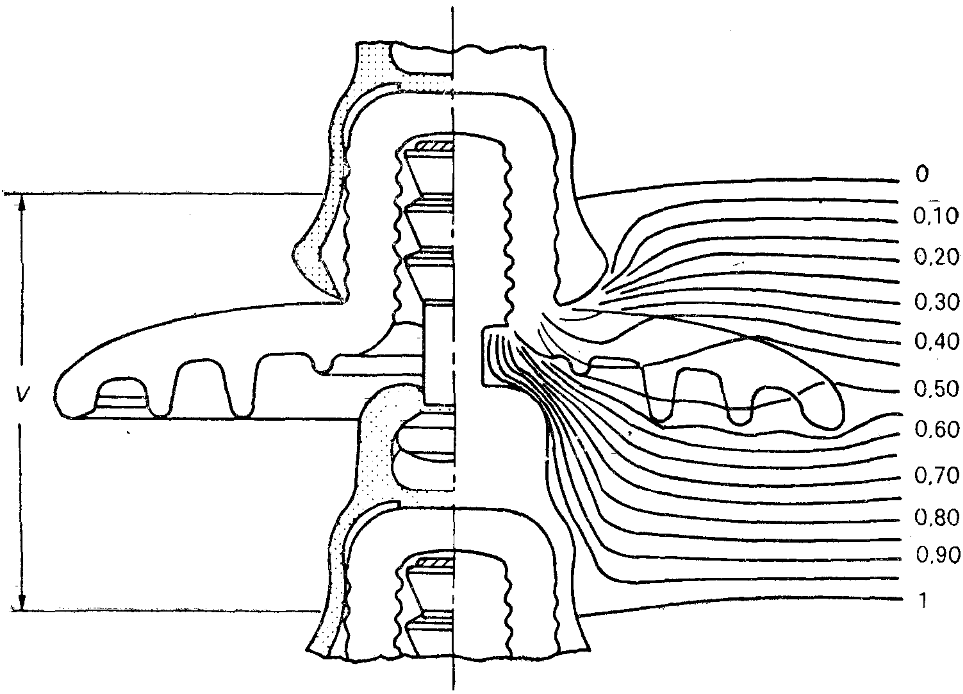


FIG. 1 EQUIPOTENTIAL LINES FOR CLEAN AND DRY INSULATOR UNITS

3.2.1 The current pulses producing the radio noise on a clean and dry insulator do not differ substantially between positive and negative polarity and, generally, the pulses occur between the zero and peak values of the applied power frequency voltage. The shape of these pulses and, consequently, the cut-off frequency of their spectrum, depends on the self-capacitance of the insulator and the surge impedance of the line to which the insulator is connected. For normal values of these parameters, the cut-off frequency is about 1 MHz. The noise produced by a clean and dry insulator is, therefore, limited to frequencies up to about 30 MHz and, generally, for insulators with average characteristics,

fairly low levels are produced. Bad design and unsuitable bonding can, however, cause higher levels extending to higher frequencies. As is also the case with corona discharge at fittings, television reception is not usually affected by this type of radio noise.

If the insulator is lightly polluted and reasonably dry, for example in fair weather, the phenomenon described above is accompanied by corona discharges at surface irregularities caused by pollutants on the insulator. Generally, this second phenomenon produces less serious effects than the first so that the noise levels, except in the case of certain types of pollution, for example near chemical works, are not significantly different from, or only slightly greater than, those occurring with a dry and clean insulator.

If the surface of the insulator is clean, but damp or wet, the existence of drops of water produces pronounced corona discharges which generally, produce higher levels of radio noise than are produced by discharges from points of surface pollution. This latter phenomenon, in damp conditions, may become less important due to a better voltage distribution. The noise level is generally greater than with dry insulators but, again, it is limited to frequencies up to a few megahertz.

3.2.2 When the surface of the insulator is heavily polluted and wet, the phenomenon is completely different, since radio noise is produced by current pulses which flow when sparking occurs across the dry bands that are created by heating due to the passage of leakage currents on the surface of the insulator. The amplitude and number of these pulses depend on the voltage stress across the insulating dry bands, on the insulator shape and dimensions, on the surface conductivity of the pollutant layer and on the characteristics of the material at the surface of the insulator. The cut-off frequency of the spectra relating to these impulses may reach a few tens of megahertz and, therefore, the radio noise may also affect televison frequencies. With wet and polluted glass or porcelain insulators, the radio noise at the normal voltage stresses, that are imposed by dielectric withstand requirements, may reach much higher levels than in other conditions previously described.

These, levels may be reduced, not only by reducing the voltage stress, but also by using insulators of special characteristics. For instance, insulators made of organic material, or glass or porcelain insulators coated with grease, prevent the formation of a continuous damp layer, and therefore of leakage currents and dry bands, due to the water repelling properties of the surface. Consequently, these are adequate solutions for reducing the noise level in wet and polluted conditions. However, such insulators may no longer be noise-free when aged and their surfaces become contaminated and hence more wettable. The semi-conducting glaze type of insulator is also a possible solution, as it is characterized by relatively low noise levels in polluted conditions,

since the conducting glaze improves the control of voltage distribution and the heat caused by the current flow in the glaze maintains dry bands which are sufficiently wide to sustain the applied voltage without sparking.

4. CORRELATION BETWEEN RADIO NOISE VOLTAGE AND THE CORRESPONDING FIELD FOR DISTRIBUTED AND INDIVIDUAL SOURCES

4.1 This clause deals with the problem of the correlation between the radio noise voltage of a single source of noise as can be measured in the laboratory and the radio noise field actually generated in service by that source alone, or by a number of similar sources distributed along a line or present in a substation.

Usually, a number of single sources, with similar characteristics, are distributed along a line, for example, insulators and spacers, or are present in a substation, for example, post insulators, clamps and joints. Occasionally, however, the radio noise may be caused by just one source, for example, the noise produced by a defective insulator or a loose or faulty fitting on a line, the injected noise from a substation, or the commutation noise from an ac/dc convertor.

A single source of radio noise, for example, an insulator string, can be represented as an ideal current generator producing a current, I, and connected between the energized conductor and ground. This current can be measured directly in the laboratory by using an appropriate test circuit simulating the actual circuit in service and by connecting the object under test, which includes the noise source, to that circuit. Though the noise current is the parameter which is constant between service and laboratory conditions, the results of a laboratory measurement are usually expressed in terms of the voltage, V, across a resistance, R, of 300 Ω corresponding to about half the surge impedance of a typical line taken as a reference. The relationship between the noise voltage V, in decibels above 1 μV, and the noise current I, in decibels above 1 μA, is given by the expression:

$$I = V - 20 \log 300 = V - 49.5$$

Briefly reviewed below are methods and formulae for calculating the correlation between the above current I and the generated electric field E. These methods and formulae apply only to frequencies up to a few megahertz.

4.2 Semi-Empirical Approach and Formula

4.2.1 *Introduction* — The general approach for establishing a quantitative correlation between the radio noise current I, and the corresponding radio noise field E, includes the following steps:

a) *Single noise source*

1) Determination of the current I of the source, which can be detained directly in the laboratory from measurement of the voltage V.

2) Calculation of noise currents in each phase for the section of the line for which the profile of the radio noise field is to be calculated. This step takes into account longitudinal attenuation as well as mutual coupling between phases.

3) On the basis of the radio noise currents in the above line section, calculation of radio noise fields due to these currents at different lateral distances from the line, and

4) For each lateral distance, the aggregate field is detained by the summation of the above fields.

b) *Multiple noise sources*

1) Repetition of the calculations described for the single source for each source present in the phase under consideration, and

2) Aggregation of the noise fields for each distance from the line, calculated separately for each source on the phase under consideration.

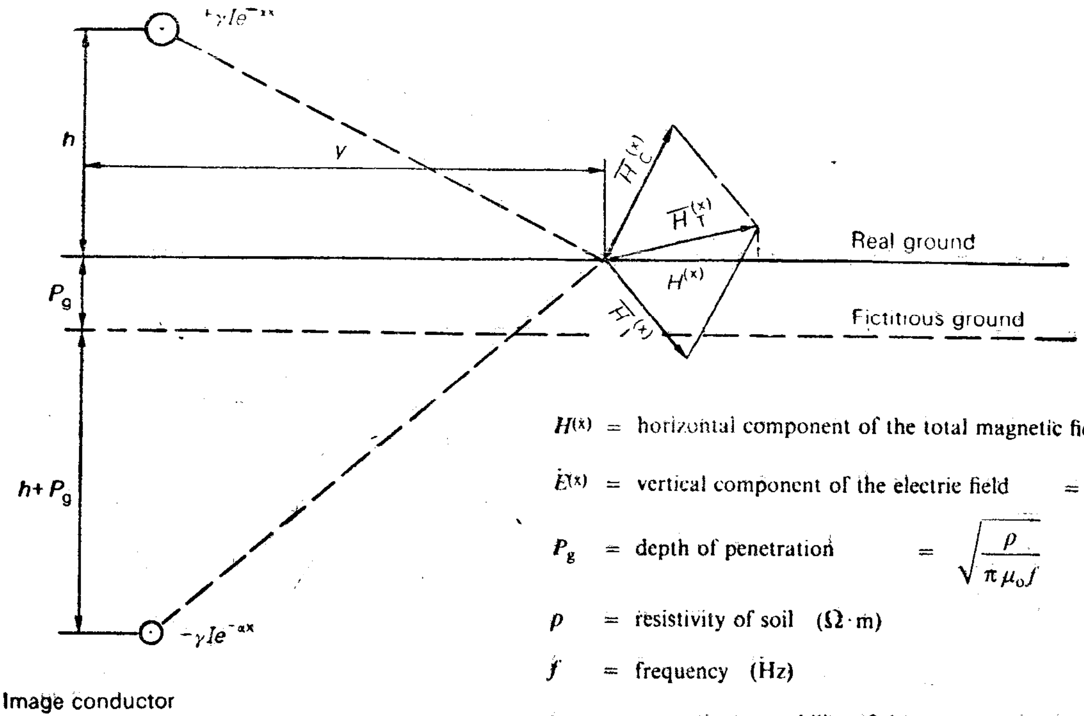
The above approach determines the electric field E_K due to the sources of noise that are present on phase k, of a line or a substation. Calculations are repeated for each phase on which noise sources are present. The aggregate field E, at each lateral distance is detained, adding 0 to 1·5 dB to the highest value of the field calculated for each phase at the particular lateral distance. In normal cases involving three-phase lines, with the same distributed sources on each phase, the correction derived from the above rule is generally lower than 1 dB and hence it can be neglected. The aggregate field, E can, therefore, be evaluated by considering the sources of noise on the nearest phase only.

4.2.2 *Formulae* — On the basis of the above approach, the following semi-empirical formulae can be obtained:

a) *Single noise source*

1) In the case of lines with only one conductor, for example, a monopolar dc line, the electric field E (x), in decibels above $1 \mu V/m$, at a longitudinal distance x, in kilometres, from the injection point of the noise source current I, in decibels above $1 \mu A$, and at a given lateral distance y, in metres, from the line, can be expressed by the following formula:

$$E(x) = I + A - Bx + C \qquad \ldots (1)$$



$H^{(x)}$ = horizontal component of the total magnetic field $\overline{H}_T^{(x)}$

$E^{(x)}$ = vertical component of the electric field = $120\pi \cdot H^{(x)}$

P_g = depth of penetration = $\sqrt{\dfrac{\rho}{\pi \mu_o f}}$

ρ = resistivity of soil (Ω·m)

f = frequency (Hz)

μ_o = magnetic permeability of the air = $4\pi \cdot 10^{-7}$ H/m

γ = splitting factor = $\dfrac{Z_1}{Z_1 + Z_2}$

Z_1 and Z_2 are surge impedances of the line

FIG. 2 DETERMINATION OF THE MAGNETIC FIELD FROM AND PERPENDICULAR TO A SECTION OF A LINE, AT A DISTANCE x FROM THE POINT OF INJECTION OF NOISE CURRENT I.

where A takes into account the splitting of the injected current on either side of the injection point. It can be calculated by means of the formula

$$A=20 \log \frac{Z_1}{Z_1+Z_2}$$

where Z_1 and Z_2 are the surge impedances of the two sections on either side of the injection point. In the most common case of a single source of noise on a long line, for example a defective insulator $Z_1=Z_2$ and then $A=-6$ dB.

The term Bx expresses the attenuation of the current along the line. The coefficient B, in practice, lies between 2 and 4 dB/km; and average value of 3 dB/km can be assumed for frequencies around 0·5 MHz.

C expresses the correlation between the strength of the noise field and the noise current in the section of the line where the field isto be calculated. It can be determined experimentally, but it can also be determined by making use of the following formula (for the meaning of the symbols *see* Fig. 2):

$$C=20 \log \left[60\left(\frac{h}{h^2+y^2}+\frac{h+2\,P_g}{(h+2P_g)^2+Y^2}\right)\right]$$

For a direct distance from the conductor of 20 m, that is to say, the reference position, the value of C lies between 7 and 12 dB.

2) In the case of three-phase lines, a similar semi-empirical formula can be used for the determination of the field $E(x)$ produced by the nearest phase:

$$E(x)=1+A+F(x)+C \qquad \ldots(2)$$

The most important difference between the two cases represented by the formulae (1) and (2) is that in the case of a three-phase line, the longitudinal attenuation cannot be expressed by means of only the attenuation constant; in this case, the definition of an attenuation function $F(x)$ is necessary. Figure 3 shows an average trend of this attenuation function, based on the result of experiments performed on high voltage and extra high voltage lines. The other symbols in formula (2) are the same as in formula (1).

b) *Multiple noise sources*

1) In the case of lines with only one conductor, the field E, due multiple noise sources equally distributed along the conductor, can be expressed by the formula:

$$E=I+A-10 \log (\alpha s)+C \qquad \ldots(3)$$

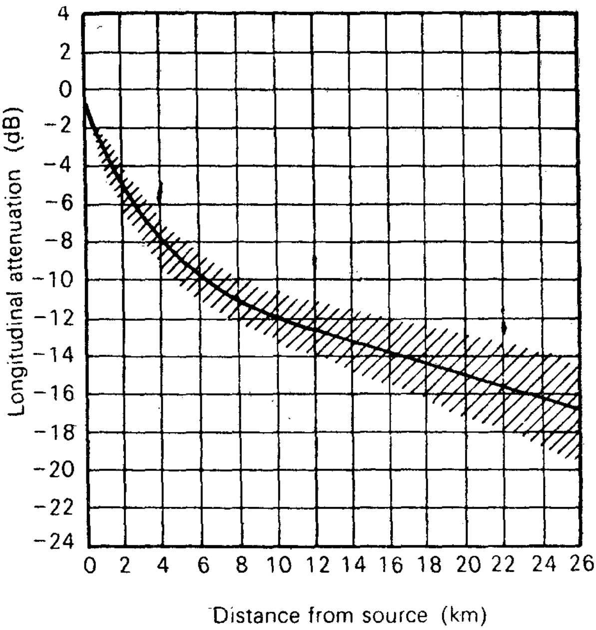


FIG. 3 LONGITUDINAL NOISE ATTENUATION VERSUS DISTANCE FROM NOISE SOURCE (FROM TEST RESULTS OF VARIOUS EXPERIMENTS FREQUENCIES AROUND 0·5 MHz)

A and C are the same as in formula (1); s is the distance between sources in metres ; a is the attenuation constant per metre and it is related to coefficient B of formula (1) by means of the relationship:

$$a=(b/8{\cdot}7).10^{-3}$$

The range of values assumed by coefficient a per metre, corresponding to the range of B given in the preceding paragraph, is between 250×10^{-6} and 450×10^{-6}. Formula (3) applies to lines of infinite length and for shorter lines, appropriated corrections can be applied.

2) In the case of three-phase lines, the field E, due to distributed sources of noise on the three phases, can be calculated as follows:

$$E=I+A+[D-10\log(s/500)]+C \qquad \ldots(4)$$

where the term D—10 log (s/500) takes into account, the aggregation of the noise sources along the line on the basis of an average attenuation law given in Fig. 3. Average values of D lie between 10 and 12 dB. Formula (4) also applies to lines of infinite length and for shorter lines, appropriate corrections can be applied.

4.3 Analytical Methods — The correlation between noise current and noise field can also be evaluated by means of analytical methods similar to those already described in case of corona effect on conductors. When the radio noise current I, generated by an individual source on a conductor and injected into the conductor, is known, the determination of the radio noise field E, produced at a given position with respect to the conductor, is carried out by considering in the first place, the splitting of the current I between the two sections of line, as seen from the injection point. For example, in the case of a source of noise on a line of infinite length, the current is divided equally between the two sections of the line. The attenuation of the current propagating along the conductor is then calculated and finally, the field produced by the current at a given position is evaluated.

In the case of lines with only one dc conductor, for example, a monopolar dc line, the calculation process is relatively simple, as all it calls for is a knowledge of the attenuation constant as a function of the frequency and the resistivity of the soil.

In case of lines with more than one conductor, three-phase ac lines, bipolar or homopolar dc lines, the calculation of propagation of noise is less simple and is generally dealt with by modal analysis. The complete modal theory is relatively complex and various more or less simplified procedures have been developed. The principle, however, remains substantially the same and the actual system of radio noise currents, or voltages, is reduced to a few simple systems, characterized by simpler laws of propagation similar to those that exist for a system with only one conductor. It is then a question of applying similar calculations to each system and then aggregating the individual fields in order to determine the resultant field.

Where several sources are distributed on one of the three phases, the calculation process is much the same as previously described for the single source. In this case, account has only to be taken of the aggregation of the various sources of noise which are usually assumed to be of the random type.

In the case of noise sources on all three phases, the calculation of the field is carried out separately for the noise injected into each phase, and the total field E is obtained by the same processes as those described in **4.2.1**.

4.4 Example of Application — An example using the analytical method described above has been worked out with reference to a 420 kV line of infinite length having an average span length of 400 m and insulator strings producing a radio noise voltage. When referred to 300 Ω, of 49·5 dB above 1 μV, that is, a current of 1 μA per string. These calculations have been performed by using suitable computing programs and the results are summarized in Fig. 4 which also gives the data assumed in the calculations.

If the calculations are repeated using the semi-empirical formula (4) with reference to the position of 20 m from the nearest conductor and assuming an average value for D of 11 dB, the following value is obtained for the electric field:

$$E = 0 - 6 + 11 - 10 \log \frac{400}{500} + 20 \log 60 \frac{2 \times 9}{20^2}$$

$$= 14{\cdot}5 \text{ dB above } 1\ \mu V/\text{m}$$

This is in good agreement with the value of 13·5 dB calculated by the analytical method (*see* Fig. 4).

5. INFLUENCE OF AMBIENT CONDITIONS

5.1 The qualitative information on the effect of ambient conditions such as humidity, rain, fog, pollution, on the radio noise levels of insulations and fittings is given in 3. This information is based essentially on a simplified analysis of the physical phenomena involved in the various situations. The knowledge of these physical phenomena is generally sufficient to establish qualitative variation laws of the radio noise levels as a function of the main parameters characterizing the surface conditions of the insulators and fittings. On the other hand, some uncertainties still exist on the quantitative effects of these parameters. In particular, some results of radio noise tests performed by different experimeters on lightly polluted insulators, specially in dry conditions, are not quite consistent. There is at present no agreed procedure for simulating in the laboratory, the most common service conditions of lightly polluted insulators, nor for the implementation of any relevant test results.

5.2 The matter is under consideration and will be reviewed when the results of studies within CIGRE yield agreed and conclusive data.

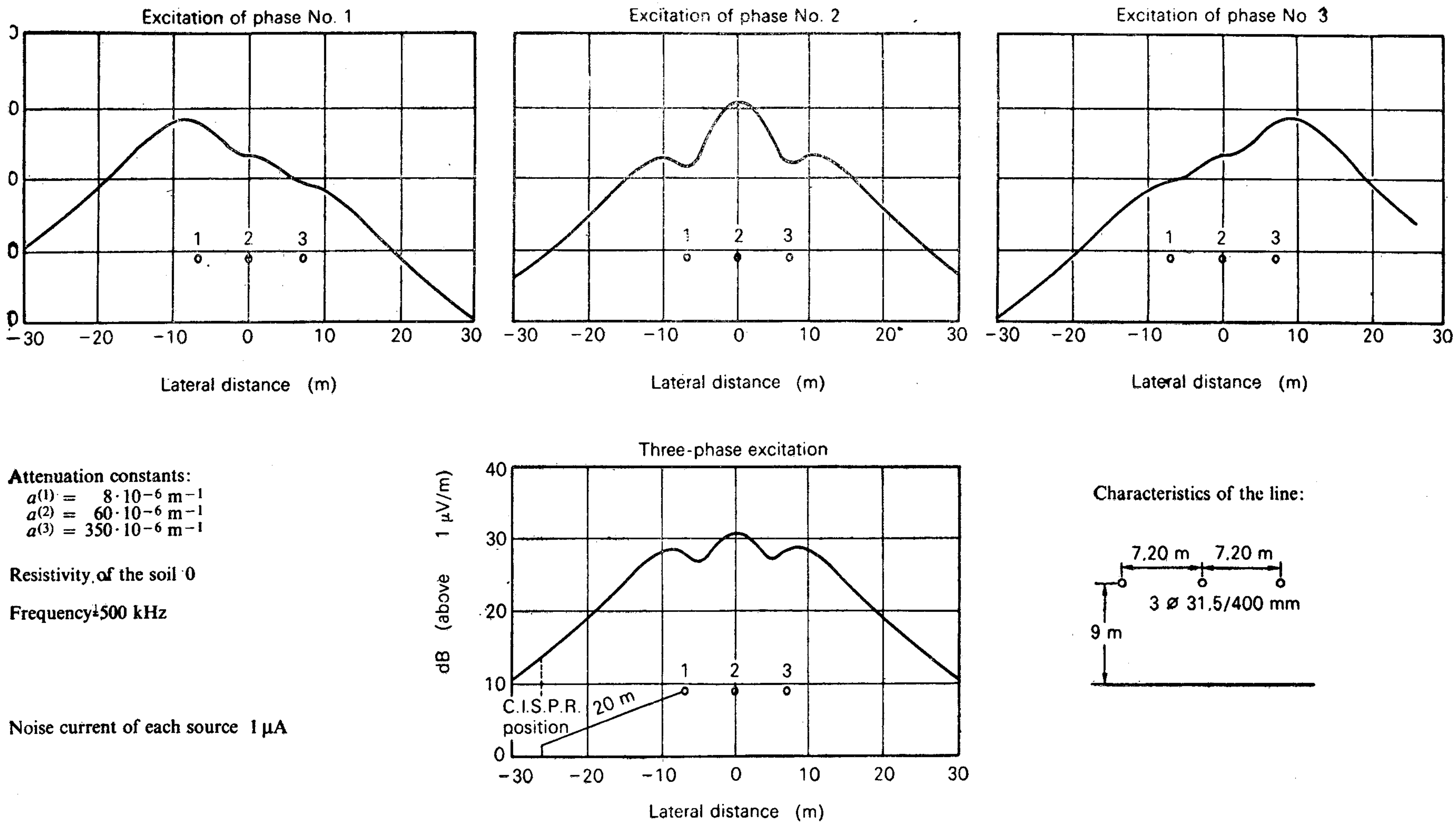


FIG. 4 LATERAL PROFILE OF RADIO NOISE FIELD PRODUCED BY DISTRIBUTED DISCRETE SOURCES ON A 420 kV LINE OF INFINITE LENGTH

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Printed at Swatantra Bharat Press, Delhi (India)